BOND STRESS OF LAP REINFORCED CONCRETE BEAMS

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A THESIS

PRESENTED BY

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BOND STRESS

OF

LAP REINFORCED CONCRETE BEAMS.

INTRODUCTION.

1. PRELIMINARY:-

Numerous tests have been made on reinforced concrete beams, but in the majority of cases, these tests were undertaken primarily to demonstrate either the advantage of certain patented shapes of reinforcing, to demonstrate the safety of a particular design or to obtain data on continuous reinforcing. Very few, if any, have had the aim and purpose of securing data and reliable information for the formulating of some general and rational method of design, such as to give a reinforced concrete beam, its required strength, economy of section area and necessary "lap of reinforcing over supports or at the center of the beam." In consequence very little is known in regard to the bond stress of lap reinforced concrete beams for use in the construction of reinforced concrete buildings.

The object and purpose of this thesis is primarily to secure, the bond stress of lap reinforced concrete beams, using either (1/2") one half inch plain rods or square twisted rods as reinforcing, placed in such a manner as to give three different lengths of lap, at the center, namely (4") four inch lap, (8") eight inch lap, or (12") twelve inch lap.

2. SCOPE OF THESIS.

Twenty beams of varying lengths of lap and kind of reinforcing, comprising (6) six different distinct sets, had been made up, but owing to accidental failures, the

data for only 12 beams was secured. The six sets of beams were as follows.

(1)

Four beams each reinforced with four 1/2" plain rods, each 2'-10" long, placed in beam parallel to 4" face giving 4" lap at the center.

(2)

Four beams each reinforced with four 1/2" plain rods, each 3'-0" long, placed in beam parallel to 4" face giving 8" lap at the center.

(3)

Four beams each reinforced with four 1/2" plain rods, each 3'-2" long, placed in beam parallel to 4" face giving 12" lap at the center.

(4)

Two beams each reinforced with four 1/2" square twisted rods each 2'-10" long, placed in beam parallel to 4" face giving 4" lap at the center.

(5)

Two beams each reinforced with four 1/2" square twisted rods each 3'-0" long, placed in beam parallel to 4" face giving 8" lap at the center.

Two beams each reinforced with four 1/2" square twisted rods, each 3'-2" long, placed in beam parallel to 4" face giving 12" at the center.

The beams were 5'-0" long, 6" wide and 4" deep. They were made of a 1:2:4 mixture reinforced with 1/2" plain or square twisted rods of medium steel placed about 3/4" from the surface. The age of the specimens when tested varied from 33 days to 51 days.

Deflections at the center point of the beams were taken in a continuous set of readings, until beam had failed; the deflectometer was then removed and the beam was broken. Deflection curves have been plotted, showing relation between loads and deflections.

The action of each beam with either shape of rods as reinforcing, under varying loads, and the method of failure in each case with the different lengths of lap was carefully noted. The difficulties encountered have also been noted, and from this experience, a discussion of lap reinforced concrete beams, and various suggestions follow.

3; ACKNOWLEDGMENTS.

The specimens were made in a special laboratory provided by the Armour Institute of Technology and were tested in the Strength of Materials laboratory of the Mechanical Engineering Departments; the work being made possible by the financial assistance of the department

of Civil Engineering.

Acknowledgment is due Mr. Stanley Dean for invaluable assistance, and encouragement to Mr. W. F. Dietzsch for valuable suggestions, and to Mrs. Julia Beveridge for furnishing references.

MATERIALS, TEST PIECES, TESTING MACHINES, AND METHOD OF PROCEDURE IN CONDUCTING TESTS.

4. GRAVEL:-

The gravel was clean and sharp, varying in size from 1/2" to 1 1/2".

5. SAND:-

A good quality of graded and clean torpedo sand was used.

6. CEMENT:-

The Chicago A.A. Portland Cement, manufactured by the Chicago Portland Cement Company was used.

7. CONCRETE:-

The concrete was made by the writers of this thesis. A 1:2:4 mixture was used, the materials being proportioned by a measuring box, whose volume was 1/8 cubic feet. The cement and sand were mixed thoroughly while dry, the aggregate, then was added, and the complete mixture was turned over with shovels, until an equally proportioned mixture was obtained. Water was then slowly added, while mixing, until a rather wet mixture was attained.

Table 1 gives the compressive strength of the various batches of concrete made up.

(8) STEEL:-

The steel used as reinforcing was rather soft and ductile. The yield point was about 34,000#. Plain rods and square twisted bars of 1/2" diameter were used exclusively.

(9) FORMS:-

The forms were made of a 2" stuff, and were so constructed as to give beams 5' x 6" x 4". Two iron bolts 12" from the ends, and iron ties at the center and at each end of the forms, prevented the latter from bulging upon depositing of concrete.

(10) BEAMS:-

As already stated twenty (20) beams were made, each being 5'-0" long, 0'-6" wide and 0'-4" deep. The beams were reinforced with either 1/2" plain rods or square twisted bars, placed in such a manner as to be 4'-8" in length, 0'-2" at each end of beam for the concrete, and giving three different laps at the center, namely 4" lap, 8" lap, and 12" lap.

Table 2 gives all beams that were made and shows; method, kind, lap of reinforcing, and data of make.

11 STORAGE OF BEAMS:-

At the expiration of forty eight (48) hours the beams were removed from the forms, of which there were four in number, and were stored away in one corner of the laboratory

until they had seasoned. They were then carried to the testing laboratory and tested.

12. TESTING MACHINES:-

Three different machines were used. The six inch concrete cubes were tested on the 200,000# Riehle Machine, the Steel rods on the 60,000# Olson Machine, and the Beams were tested on the 20,000# Riehle Machine. The latter machine was used for the reason that it could only be run by hand power, and extreme care had to be taken in securing correction deflections for different increments of load.

13. METHOD OF PROCEDURE IN CONDUCTING TESTS:-

The beams were tested at their third points, the tests being performed for the purpose of securing data on the bond stress of lap reinforced concrete beams.

Owing to lack of head room, the beams had to be reversed in the machine, the top of beam being on the bottom and visa versa, this necessitated the beam resting on knife edges at its third points, but made no difference in the tests or results obtained from same. The deflectometer also had to be changed to meet the conditions under which the tests were run.

Plate 2 shows beam in place, ready to be tested.

GENERAL DISCUSSION AND DATA SECURED.

(14) DISCUSSION OF RESULTS OF TEST.

The beams were designed to fail by slipping of bars, but owing to the rising of the steel rods out of their true position, the necessary stress was not induced in the steel and the beams failed instead by crushing of the concrete. From the data secured however, it is seen that a bond stress of 60# per square inch is a safe working stress, as no failure occured by slipping of bars at bond stresses varying from 146 to 392# per square inch.

Assuming a bond stress of 60# per square inch, the necessary length to lap bars over supports or at center of beams will be

$$L = \frac{f_s}{4u} d = \frac{15,000}{4 \times 60} d = 62\ 1/2\ d.$$

(as per Turneaure and Maurer.)

The formulae used for figuring the bond stress at the center of the beams, were

(1)

$$T = \frac{M}{jd} \qquad \text{for total tension in steel}$$

where T is total tenstion in steel; M, the bending moment, and j the ratio of the resisting couple to d, d being the distance from the compressive face to the plane of the steel.

(2)

$$S = \frac{T}{\Sigma o \times lap}$$ For unit bond stress

where S is the unit bond stress, T the total tension, the summation of the perimeters and lap, being the distance in inches that the rods are lapped at the supports or at the center of the beams.

(3)

to obtain values for fc, the unit fibre stress in concrete at its compressive face, at the loading when cracks first appeared, the following formula was used

$$Mc = fc \times 1/6\ bd$$

$$fc = \frac{6\ Mc}{bd}$$

where Mc is the resisting moment as determined by concrete, b is the breadth of a rectangular beam and d the distance from the compressive face to the plane of the steel.

The values of T, fc, and S were secured when first tension cracks appeared and when final load was applied.

The above formulae were derived with necessary corrections due to lapping of reinforcing, from Turneaure and Maurer's book on "Principles of Reinforced Concrete Construction."

15. CURVES:-

The curves as plotted show the loads applied and corresponding deflections.

The loads were used as ordinates and delections as abscissas as plotted, they show that the beams deflected more or less uniformily up to maximum loading, where upon the deflec-

tions increased more rapidly than the loads applied.

(16) MaNNER OF FAILURE:-

Owing to the fact that the steel bars moved from their true position, while concrete was being rammed and tamped, the bars never received the stress they were capable of receiving, the result being, that the beams failed by crushing of concrete either at their third points or at their supports.

The average maximum loading taken by the beams with the 4" lap was 866# that taken by those with 8" lap was 1806# and by those with 12" lap was 1886#, showing little difference in maximum loading for the last two sets of reinforcing. Nevertheless the writers believe that if lapped reinforced concrete beams are to be used, the lapping either at the center or over the supports should never be less than 12".

March-10-1911 Beam — Jan-25 8"L 4R W		
Loads(#)	Deflection	
	Reading	Actual(")
0	443	0
350	443	0
400	4427	.0003
450	4425	.0005
500	4423	.0007
520	4422	.0008
590	4421	.0009
610	4414	.0016
660	4410	.0020
720	4400	.0030
840	4388	.0042
880	4380	.0050
960	4370	.0060
1050	4359	.0071
1150	4340	.0090
1270	4330	.010
1370	4320	.011
1480	4300	.013
1580	4290	.014
1670	4270	.016
1730	4259	.017
1810	4240	.019
1880	4211	.0219
1890	4180	.025
1920	4142	.0288
1820	4090	.0344
1730	4031	.0399

March-15-1911 Beam - Jan-23 8"L 4-R X		
Loads [*]	Deflection	
	Reading	Actual
100	411	0
200	410	.001
300	409	.002
410	408	.003
530	407	.004
610	405	.006
710	403	.008
Cracks appear - see sketch		
800	403	.008
870	401	.010
920	398	.013
1000	397	.014
1050	396	.015
1100	394	.017
1150	391	.020
1150	388	.023
1120	387	.024
1100	384	.027
1070	384	.027
1020	378	.033
1010	374	.037
1000	371	.040
1000	369	.042
950	366	.045
940	362	.049
920	360	.051
910	356	.055
900	354	.057
870	352	.059
840	340	.071
830	335	.076

March-15-1911		
Beam - Jan-25 8"L 4R X		
Loads(#)	Deflection	
	Reading	Actual(")
50	405	0
150	405	0
250	404	.001
290	404	.001
410	390	.015
500	370	.035
560	360	.045
660	320	.085
760	290	.115
860	260	.145
910	242	.163
1000	210	.195

March - 15 - 1911		
Beam - F 10 12" L 4 R X		
Load(#)	Deflection	
	Reading	Actual(")
140	392	0
210	391	.001
310	390	.002
580	389	.003
960	389	.003
1020	389	.003
1140	389	.003
1230	388	.004
1330	388	.004
1440	387	.005
1530	387	.005
1630	386	.006
1730	385	.007
Cracks first appear		
1830	384	.008
1920	384	.008
2020	383	.009
2120	382	.010
2190	381	.011
2260	380	.012
2330	380	.012
2380	379	.013
2440	379	.013
2450	378	.014
2490	377	.015
2490	377	.015
2490	377	.015
2360	377	.015
2260	378	.014
2010	379	.013
1810	381	.011

March - 15 - 1911

Beam - F 10 12"L 4 R

Load(#)	Deflection	
	Reading	Actual (")
60	446	0
150	446	0
240	446	0
350	443	.003
480	440	.006
640	438	.008
780	436	.010
860	435	.011
950	434	.012
Cracks appear		
1000	433	.013
1070	431	.015
1120	430	.016
1190	429	.017
1250	428	.018
1300	426	.020
1360	425	.021
1410	423	.023
More cracks		
1460	422	.024
1500	421	.025
More cracks		
1500	417	.029
1500	412	.034
1490	405	.041
1480	398	.048
1380	398	.048
1200	383	.063
1050	370	.076
1010	364	.082
990	356	.090

March-22-1911		
Beam - F10 12"L 4R Z		
Loads(*)	Deflection	
	Reading	Actual(**)
180	418	0
300	417	.001
395	417	.001
650	416	.002
790	415	.003
950	414	.004
1090	413	.005
1100	412	.006
1420	408	.010
Cracks - see sketch		
1500	407	.011
1550	406	.012
1550	403	.015
1630	401	.017
1690	398	.020
1700	395	.025
1700	391	.029
1650	387	.033
1600	382	.038
1600	378	.042
1550	374	.046
1520	370	.050
1450	364	.056
1400	361	.061
1380	356	.066
1240	348	.074
1180	341	.081
1020	336	.086

March-29-1911

Beam - F 15 8"L 4R XT

Load (#)	Deflection	
	Reading	Actual (")
110	418	0
200	418	0
200	417	.001
700	415	.003
860	414	.004
950	413	.005
1050	412	.006
1130	412	.006
1280	411	.007
Crack between support & one Knife edge		
1400	410	.008
1530	409	.009
1650	408	.010
Hair cracks - near same Knife edge		
1760	407	.011
1870	406	.012
1990	405	.013
2100	404	.014
2200	402	.016
Cracked at centre		
2280	400	.018
2200	396	.022
1150	368	.050
1100	357	.059
1000	345	.071
900	332	.084
840	321	.095
810	309	.107
800	298	.118

April-5-1911 Beam – F17 4"L 4R BT		
Load(#)	Deflection	
	Reading	Actual(")
70	382	0
500	380	.002
700	374	.008
780	366	.016
Cracked in middle		
760	354	.028
630	340	.042
420	323	.059
350	301	.081
290	281	.101
250	261	.121
200	228	.154

April-5-1911 Beam- M1 4"L 4R Z		
Loads(#)	Deflection	
	Reading	Actual(")
60	372	0
430	370	.002
630	367	.005
820	361	010
Cracks in middle		
740	347	.024
680	333	.038
640	320	.051
600	298	.073
570	277	.094
570	257	.114
530	238	.133
550	220	.151
500	199	.172
500	177	.194
480	157	.214

April-5-1911 Beam - M3 12"L 4R X T		
Load(#)	Deflection	
	Reading	Actual(")
80	326	0
160	326	0
250	326	0
420	324	.002
650	322	.004
820	320	.006
Crack over one Knife edge		
980	318	.008
1150	316	.010
1250	313	.013
Crack 2½" from Knife edge		
1360	310	.016
1450	307	.019
1450	303	.023
1500	299	.027
1530	294	.032
1500	289	.037
1400	283	.043
1300	276	.050
1230	268	.058
1100	261	.065
1020	253	.073
980	244	.082
Crushing at middle		
900	236	.090
880	229	.097
820	218	.106
790	206	.118
730	194	.130

April-7-1911 Beam - F24 12"L 4R R		
Loads(*)	Deflection	
	Reading	Actual(=)
70	348	0
230	348	0
320	347	.001
500	346	.002
720	345	.003
Crack over one Knife edge		
880	344	.004
1060	342	.006
Crack near other Knife edge		
1170	341	.007
1360	340	.008
Cracks outside each Knife edge		
1470	339	.009
1600	337	.011
1700	335	.013
1720	332	.016
1600	326	.022
1050	315	.033
980	306	.042
810	298	.050
710	290	.058
610	278	.070
520	263	.085

April-7-1911

Beam - M1 12"L 4R A.T.R.

Loads(34)	Deflection	
	Reading	Actual(11)
70	347	0
250	347	0
390	346	.001
630	344	.003
850	343	.004
1000	341	.006
1140	339	.008
Crack over one Knife edge		
1240	336	.011
1240	332	.015
Crack 2" inside other Knife edge		
1240	327	.020
1180	322	.025
1110	313	.034
1020	305	.042
1000	298	.049
920	291	.056
880	284	.063
820	277	.070
750	265	.082
680	252	.095
580	235	.112

COMPRESSION TEST OF 6" CUBES

Concrete as in Beam	Age Days	Crushing Load	Strength lbs./sq. in.	Remarks
F10, 12"L, 4R, Z	42	54840	1525	
F15, 8"L, 4R, Z T.R.	37	42850	1190	
F15, 8"L, 4R, X	37	57750	1600	Lopsided
F17, 4"L, 4R, B T.R.	35	53030	1475	
F10, 12"L, 4R	42	61980	1725	
F17, 4"L, 4R, D T.R.	35	36380	1011	
F10, 8"L, 4R, A T.R.	42	39610	1110	Lopsided
J25, 8"L, 4R, W	58	79060	2200	
J23, 8"L, 4R, W	60	67660	1885	
J25, 8"L, 4R, X	58	88800	2470	
J19, 4"L, 2R, X	64	74320	2065	
J19, 4"L, 2R, Y	64	55510	1500	Lopsided
J19, 4"L, 4R, W	64	79500	2250	
M1, 12"L, 4R, A T.R.	36	43290	1200	
F24, 12"L, 4R, R	40	37160	1035	Lopsided
M1, 4"L, 4R, X	36	50230	1400	
M1, 4"L, 4R, Z	36	70670	1920	
M3, 12"L, 4R, X T.R.	34	41230	1145	

BEAM DATA

Beam	Age - Days	Rods	Lap	Remarks
J19-Y	48	2 Plain	4 in.	Not Tested
J19-Z	———	2 "	4 "	" "
J19-X	———	2 "	4 "	" "
J19-W	———	4 "	4 "	" "
J23-W	42	4 "	4 "	" "
J23-X	51	4 "	8 "	
J25-W	44	4 "	8 "	
J25-X	49	4 "	8 "	
F10-	33	4 "	12 "	
F10-X	33	4 "	12 "	
F10-Z	40	4 "	12 "	
F15-X	42	4 "	8 "	
F15-Z	———	4 Twisted	8 "	" "
F17-A	———	4 "	8 "	" "
F17-B	41	4 "	4 "	
F17-D	———	4 "	4 "	" "
F24-R	42	4 Plain	12 "	
M1-X	———	4 "	4 "	" "
M1-Z	36	4 "	4 "	
M1-A	38	4 Twisted	12 "	
M3-X	33	4 "	12 "	

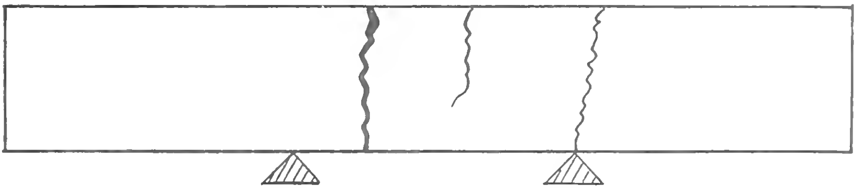
Date	No. of Rods	Lap of Rods	Distance of Rods from Bottom		FIRST CRACK			FINAL LOAD			Kind of Failure
					fc	T	s	fc	T	s	
Jan. 23 : Mar. 15	4	8"	$1\frac{1}{4}$"	X	1070#	3500#	140#	1540#	5000#	200#	COMP.
Jan. 25 : Mar. 10	4	8"	$1\frac{1}{4}$"	W	2560#	8400	333#	2560#	8400#	333	"
" " " "	4	8"	$1\frac{3}{4}$"	X	2200#	5900#	236#	2200#	5900#	236#	"
Feb. 10 : Mar. 15	4	12"	1"	–	1050#	3820#	102#	1670#	6023#	160#	"
" " : " "	4	12"	1"	X	1920#	6950#	185#	2760#	10000#	266#	"
Feb. 10 : Mar. 22	4	12"	1"	Z	1580#	5320#	142#	1890#	6360#	170#	"
Feb. 15 : Mar. 29	4	8"	$1\frac{1}{8}$"	XT	1560#	5500#	220#	2780#	9845#	392#	"
Mar. 3 : April 5	4	12"	$1\frac{3}{16}$"	X	1050#	3620#	96#	1960#	6730#	179#	"
Feb. 17 : Mar. 3	4	4"	$1\frac{3}{16}$"	B	950#	3360#	268#	950#	3360#	268#	"
Mar. 1 : April 5	4	4"	$1\frac{1}{4}$"	Z	1090#	3730#	298#	1090#	3730#	298#	"
Mar. 1 : April 7	4	12"	$1\frac{3}{16}$"	A	1440#	5100#	136#	1570#	5500#	146#	"
Feb. 24 : April 7	4	12"	$1\frac{1}{8}$"	R	1300#	4510#	121#	2100#	7400#	196#	"

fc = stress in concrete

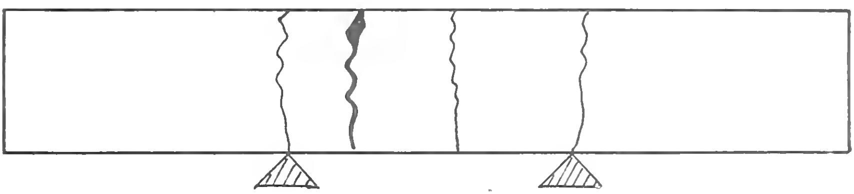
T = Total Tension in Steel

s = unit Bond Stress.

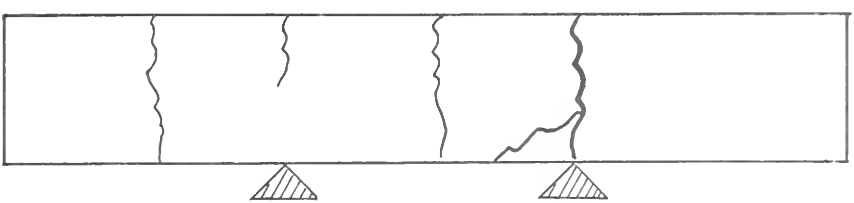
BEAM Mar. 10, 8" Lap 4 Rods W



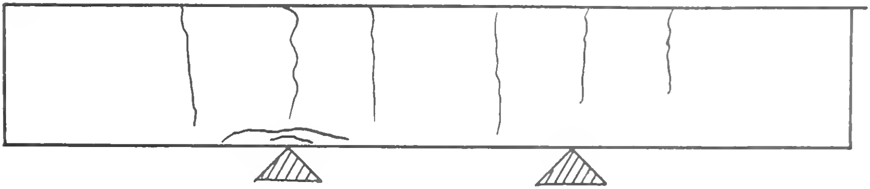
BEAM Mar 15, 8" Lap 4 Rods X



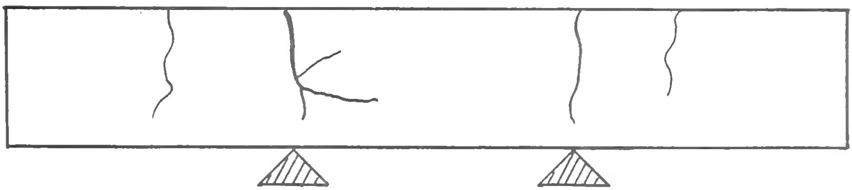
BEAM Mar. 15, 8" Lap 4 Rods. X



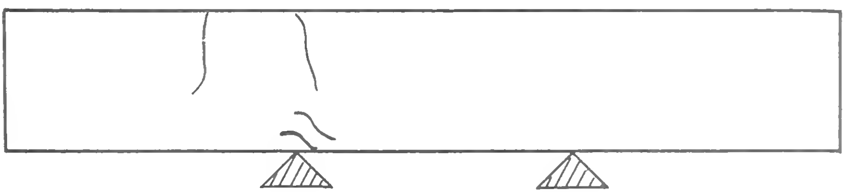
BEAM Mar. 15, 12" Lap 4 Rods X



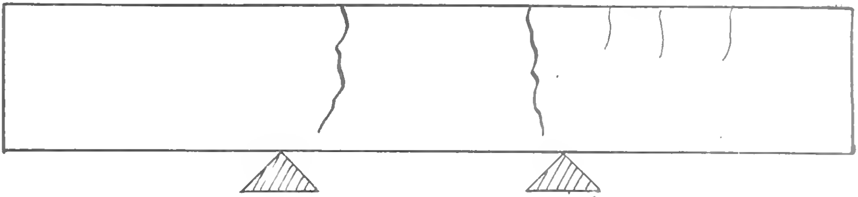
BEAM Mar. 15, 12" Lap 4 Rods No Mark.



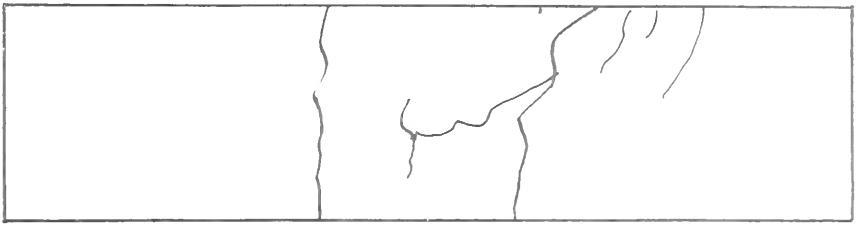
BEAM Mar. 22, 12" Lap 4 Rods Z



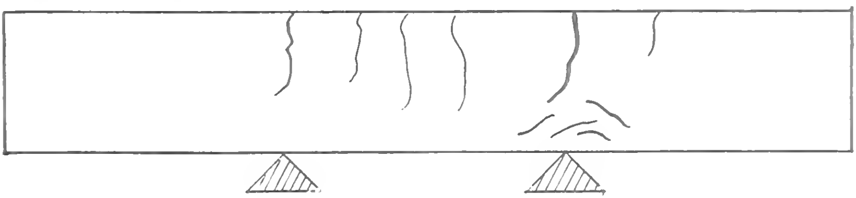
BEAM Mar. 29 8" Lap 4 Rods X Side view



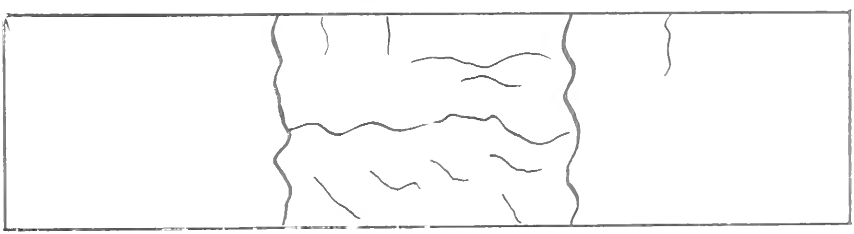
Bottom View



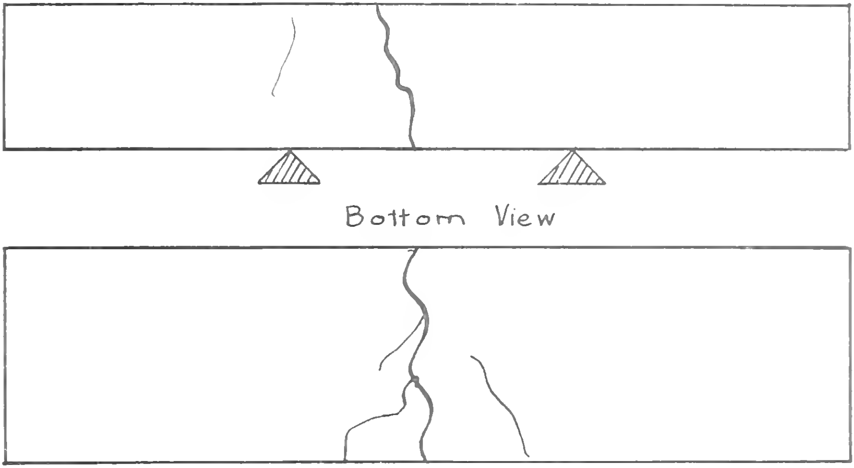
BEAM April 5 12" Lap T.R. 4 Rods X Side View



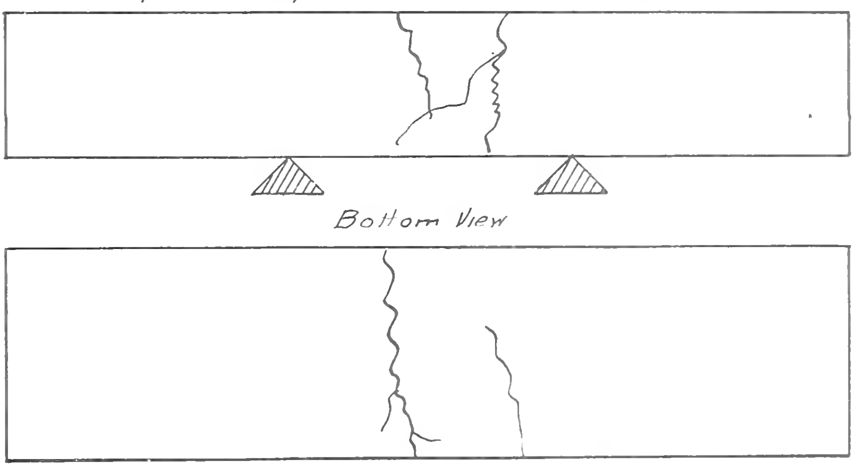
Bottom View



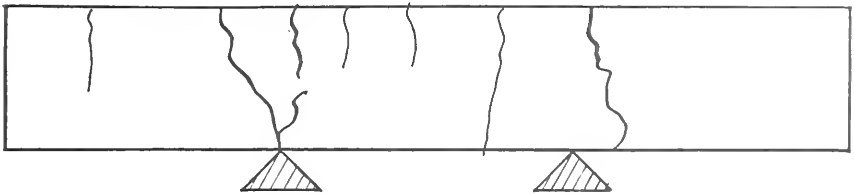
BEAM April 5, 4" Lap 4 Rods T. R. B Side view



BEAM April 5 4" Lap 4 Rods Z Side View

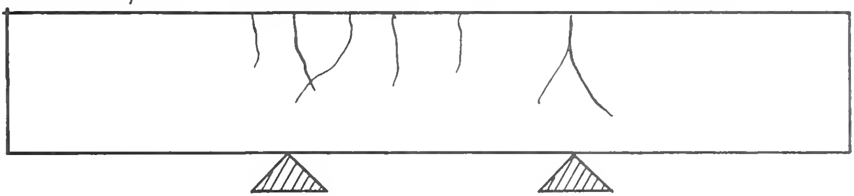


BEAM April 7 4 Rods 12" Lap R Side View

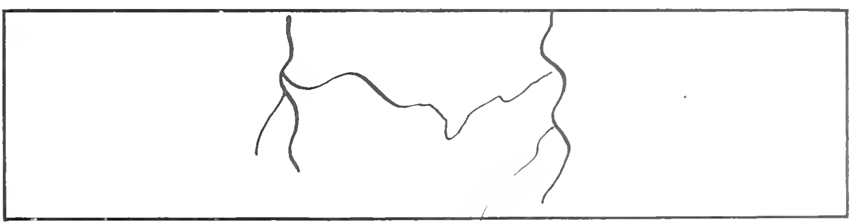


Bottom View

BEAM April 7 4 Rods 12" Lap T.R. A Side View



Bottom View



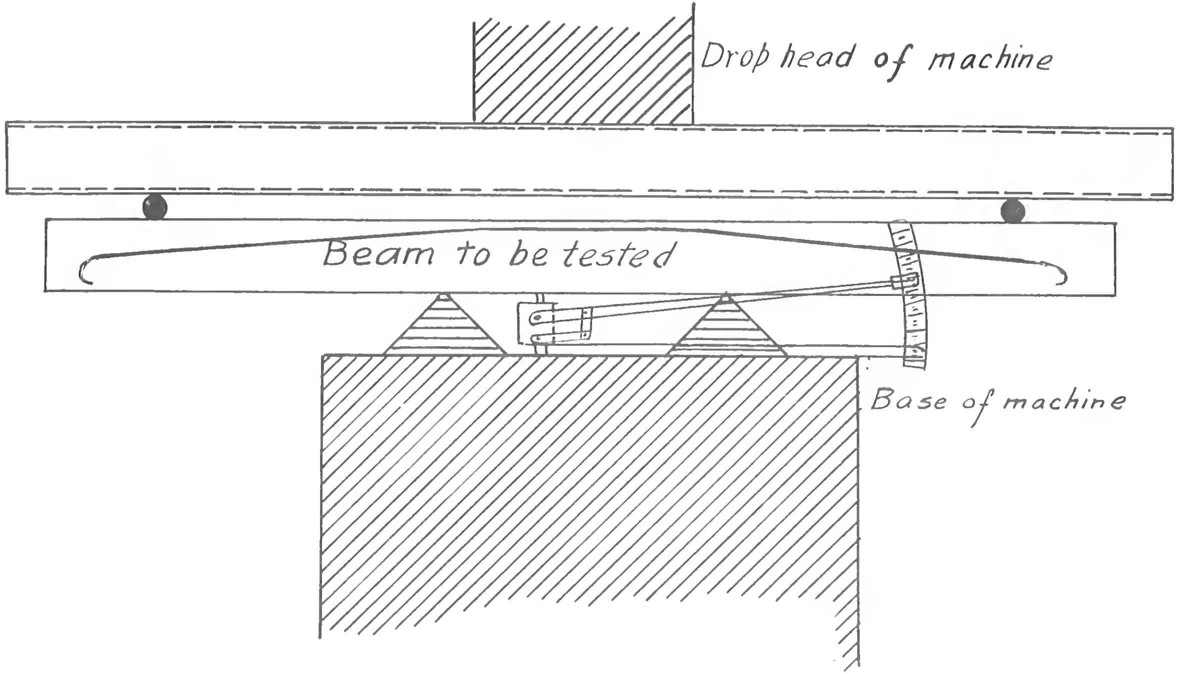


PLATE 2